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Implementation of expert system on estimation of fatigue properties from monotonic mechanical properties including hardness

Jun-Hyub Park[a], Ji-Ho Song[b]*, Taeyoung Lee[c] , Kwang-Soo Lee[d]

[a]*Dept. of Mechatronics Engineering, Tongmyong University, 179, Sinseono, Nam-gu, Busan, 608-711, South Korea*
[b]*Dept. of Mechanical Engineering, Korea Advanced Institute of Science and Technology, 373-1, Guseong-dong, Yuseong-gu, Daejeon 305-701,*
[c]*R&D institute, Hyundai elevator Co., LTD., 1-83, Dongsoong-dong, Jongro-gu, Seoul, 110-510, South Korea*
[d]*Dept. of Automobile Engineering, Hoseo University, 268, Anseo-dong, Chunan-si, Chungcheongnam-do,330-713, South Korea*

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Abstract

This paper describes implementation of the expert system on estimating fatigue properties from simple tensile data or hardness data. The fatigue properties are usually obtained by performing fatigue tests. However, as fatigue test requires time and high cost, many methods have been proposed to estimate the strain-life curves from monotonic mechanical properties including hardness. Though many useful estimation methods have been proposed and they afford every facility, a mechanical designer has some difficulties in making a decision to select the best method among the several methods for the fatigue strength design or assessment under given conditions. And then several researchers including authors evaluated the methods and proposed the best method according to material. In spite of those guidelines, it does not seem to be always easy for ordinary mechanical designer to apply. In this study, an expert system was developed to facilitate it. A commercial expert system shell, Acquire, was used and the user interfaces of the expert system were developed using Visual Basic. The expert system helps mechanical designer to select the best estimation method among methods for estimating fatigue properties from monotonic mechanical properties including hardness, depending on his or her knowledge level of fatigue and has some special functions to describe recommendation and remarks in detail and display the accuracy and predictability of estimation method.

Keywords: Fatigue properties; expert system; estimation methods; fatigue strength assessment; tensile strength; hardness

1. Introduction

Fatigue analysis is playing a vital role in the design of mechanical structures and components. Fatigue properties of materials are essential for the fatigue analysis. Fatigue properties such as stress-life(S-N) curves or strain-life(ε-N) curves are usually obtained by performing fatigue tests.

However, as the fatigue test requires a lot of time and effort, many methods have been proposed to estimate the strain-life curves from monotonic mechanical properties including hardness, will be described in detail later. And

* Corresponding author. Tel.: +82-42-350-3055; fax:.+82-42-350-3095; Mobile: +82-10-8716-2122
E-mail address: jihosong0@kaist.ac.kr

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then evaluation of the estimation methods proposed has been studied to find the best estimation method for a material by many researchers, will be described in detail later.

Based on the results obtained, some guidelines are provided for estimating fatigue properties from simple tensile data or hardness. However, a mechanical designer has some difficulties in making a decision to select the best method among the several methods for the fatigue strength design or assessment under given conditions, although they have many useful estimation methods and guidelines for selecting the most appropriate estimation method.

Recently, the use of an expert system to solve complicated engineering problems such as fatigue strength assessment which requires highly advanced expertise has been emphasized [1]. Many useful expert systems have been developed in various fields. In the field related to fractures, some expert systems for diagnosis of failure causes or mechanisms have been developed. Komai et al. [2,3] have developed expert systems which diagnose the sensitivity and causes of environmentally assisted cracking. Liao et al. [4,5] have developed an expert system for failure mechanism identification. Some expert systems in the area of fatigue are also found. McMahon et al. [6,7] have written an introduction to the utilization of expert systems in developing computer systems to support the engineering design process in the area of fatigue and fracture. However, the details of the expert system used are not clear. Ishikawa and Dai [8,9] have developed an expert system, proposing a procedure for knowledge management instead of using a commercial expert system shell. They have used the system for evaluating the fatigue strength of notched bars. However, the expert system is a very primitive one.

Lee and Liebowitz [10] have developed a material expert system for the evaluation of critical flaw size in structural components subjected to fatigue loads. However, the expert system is of limited application. Well-structured expert systems that can be utilized easily and practically in the area of fatigue can be hardly found. A major reason for it may be attributed to the fact that although a lot of useful expert's knowledge of fatigue has been practically utilized for solving various fatigue problems, the range of validity of each individual knowledge is not always well defined due to the inherent complexity of fatigue phenomena. Therefore, it is not so easy to construct a correct knowledge base in which the application range of each knowledge is clearly specified, and also hard to modify and update it continuously.

It may be mentioned that the most important element in developing an expert system for fatigue strength assessment is the construction of a correct and consistent knowledge base from extensive and diverse expert's knowledge of fatigue, based on reasonable selection criteria. A simple and currently most feasible method for construction of a reliable knowledge base for fatigue strength assessment may be to use only knowledge that has been well verified through extensive examination, and further, to modify and supplement the knowledge continuously through practical applications. There are various expert system shells available for construction of expert systems. So, if a sufficient amount of the expert's knowledge can be obtained, an expert system can be relatively easily constructed by using an expert system shell.

Based on the above-mentioned concepts the authors' group has been developing expert systems, along with fatigue strength databases and softwares, for the integrated fatigue assessment system [11-14]. The late two expert systems that can be utilized effectively for practical applications, the expert system for estimation of fatigue properties of materials and that for fatigue life prediction, was developed.

In this study, an expert system is developed to facilitate it. A commercial expert system shell, Acquire, is used and the user interfaces of the expert system are developed using Visual Basic. The expert system helps mechanical designers to select the best estimation method among methods for estimating fatigue properties from monotonic mechanical properties including hardness, depending on their knowledge level of fatigue and has some special functions to describe recommendation and remarks in detail and display the accuracy and predictability of estimation method.

2. Estimation methods for fatigue properties of materials

Fatigue properties of materials are essential for fatigue analysis. The accuracy of fatigue analysis depends significantly on the correctness of fatigue properties of materials. Fatigue properties of materials such as stress–life (S–N) or strain–life (ε–N) curves may be obtained by performing fatigue tests, or from data books or databases available. The strain-life (ε–N) curve is expressed as follows:

$$\frac{\Delta\varepsilon}{2} = \sigma_f^{'}\left(2N_f\right)^b + \varepsilon_f^{'}\left(2N_f\right)^c \qquad (1)$$

where $\Delta\varepsilon/2$, $\Delta\varepsilon_e/2$and $\Delta\varepsilon_p/2$ are total, elastic and plastic strain amplitudes, respectively, and σ'_f , b, ε'_f and c are fatigue strength coefficient, fatigue strength exponent, fatigue ductility coefficient and fatigue ductility exponent, respectively.

However, it cannot be expected that fatigue properties of material are always available whenever needed. Hence, many methods have been proposed so far to estimate strain–life curves from simple tensile data, and some of them have been utilized conveniently and successfully.

Manson [15] has first proposed two methods, namely, the four-point correlation method and universal slopes method, to estimate the strain-life curve using only tensile data. Mitchell [16] has proposed another method, particularly suitable for steels. Muralidharan and Manson [17] have proposed a new, modified universal slopes method to improve the original universal slopes method. Bäumel and Seeger [18] have proposed a new method, uniform material law. Ong [19] has proposed a modified four-point correlation method. Roessle and Fatemi [20] proposed an estimation method using hardness of materials, and Park and Song [21] proposed a new method for aluminum alloys, referred to as the modified Mitchell's method. Maggiolaro and Castro [22] proposed a new estimation method called the medians method, by performing an extensive statistical evaluation of the individual parameters of the e–N curve for 845 different metals. Recently, Lee and Song [23] proposed new relationship of ultimate tensile strength versus hardness for titanium alloys.

There are several studies on evaluation of the estimation methods of fatigue properties. Park and Song [24] first evaluated systematically all methods proposed until 1995 using published data on 138 materials. Jeon and Song [13] have evaluated seven estimation methods, i.e. Manson's original 4-point correlation method and universal slopes method, Mitchell's method, modified universal slopes method, uniform material law, modified 4-point correlation method and modified Mitchell's method, and obtained the conclusions that the modified universal slopes method provides the best results for steels and the modified Mitchell's method, for aluminum alloys and titanium alloys. Roessle and Fatemi [20] reported that their hardness method provides somewhat better results than the modified universal slopes method, for steels. Kim et al. [25] have evaluated seven estimation methods, i.e. Manson's original 4-point correlation method and universal slopes method, Mitchell's method, modified universal slopes method, uniform material law, modified 4-point correlation method and Roessle–Fatemi's hardness method, for eight steels and concluded that the modified universal slopes method, the uniform material law and Roessle–Fatemi's hardness method provide good results.

The evaluation results by Roessle and Fatemi and Kim et al. have been obtained using a conventional error criterion. Maggiolaro and Castro [22] compared their medians method with seven other estimation methods, based on the fatigue life prediction ratio (Npredicted/Nobserved). They reported that for steels, the medians method provides better results and the modified universal slopes method and Roessle–Fatemi's hardness method give reasonable results. For aluminum alloys and titanium alloys, they found that better results are obtained from their medians method, followed by the uniform material law. Particularly, they noted that the modified universal slopes method should not be applied to aluminum or titanium alloys. It can be said from the above evaluation studies that the modified universal slopes method provides excellent results, particularly for steels, and the uniform material law, the medians method and Roessle–Fatemi's hardness method also give good results for all materials. Lee and Song [23] have found that the medians method proposed by Maggiolaro and Castro provided the best estimation results for aluminum alloys.

3. Implementation of expert system for estimating fatigue properties

Based on the results published as mentioned above, some guidelines are provided for estimating fatigue properties from simple tensile data or hardness. However, it is not so easy for ordinary mechanical designers to select a suitable estimation method for conducting reliable fatigue assessment, when they do not have fatigue properties but only simple tensile data or hardness.

Therefore, an expert system helps the mechanical designers easily to obtain better estimation method if the system has more knowledge related to fatigue properties. Authors' group has also developed the expert system for selecting the best estimation method of fatigue properties[13,14]. Jeon and Song [13] developed the expert system for estimating fatigue properties from simple tensile properties which has 3 steps, as shown in Fig. 1.

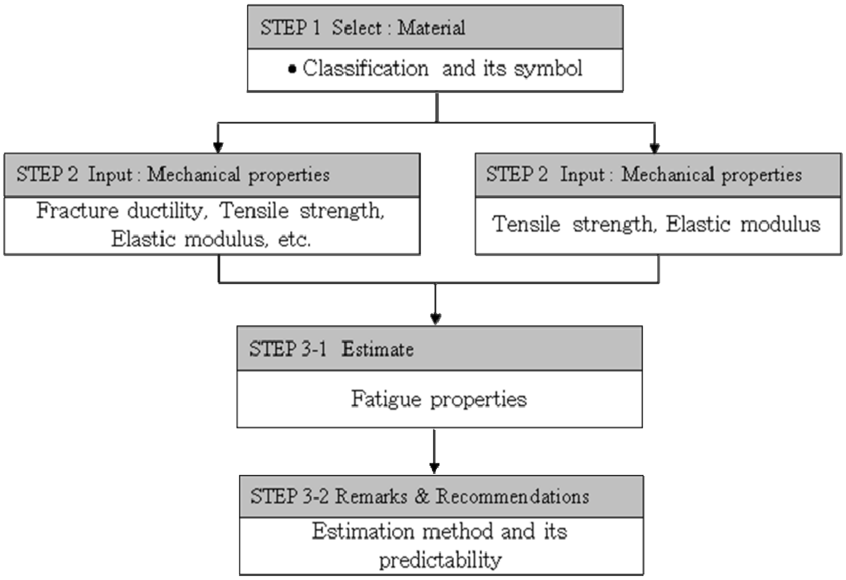

Fig. 1. Process flow of the expert system developed by Jeon and Song [13]

The expert system can infer fatigue properties of steels, aluminum alloys or titanium alloys using seven estimation methods only if the tensile strength σ_B data is available and present the accuracy and total predictability. The expert system was developed by using an expert system shell, UNIK[26], which has been developed by Professor J.K. Lee and others in KAIST. However, the expert system is needed to upgrade so that it can use ten estimation methods mentioned above, especially including estimation methods using hardness and a commercial expert system shell which can easily update knowledge about fatigue.

In this study, in order to implement a new expert system for estimating fatigue properties from simple tensile properties or hardness, the Acquire which is the commercial expert system shell developed by Acquired Intelligence in Canada is used as the inference engine, the Visual Basic is used for developing the user interface, and the ANSI/ISO standard C++, which is compatible with MS or Borland C is used for developing algorithm of mathematical calculation process. The knowledge base in the expert system developed consists of six rules and three objects for inferring a tensile strength when hardness is only available and seven rules and three objects for inferring fatigue properties. The rules and objects are described, using rule-and object-editors provided by the expert system shell, Acquire. Forward chaining is employed for the expert system. Figure 2 shows the process flow of the expert system developed in this study.

At step 1 in the Fig. 2, users must select one among the classifications, material symbol and code of material standard as some prior knowledge about material to be analyzed, as shown in Fig. 3 (a). The information inputted in this step would be utilized for inferring the most appropriate estimation method and is needed for the expert system to find the best estimation method with the highest accuracy and total predictability in inference, which is one of the main features of the expert system. Here, for convenience, the accuracy and total predictability are expressed by the values of $E_f(s)$ and $\bar{E}$ described in the references 13, 24, respectively.

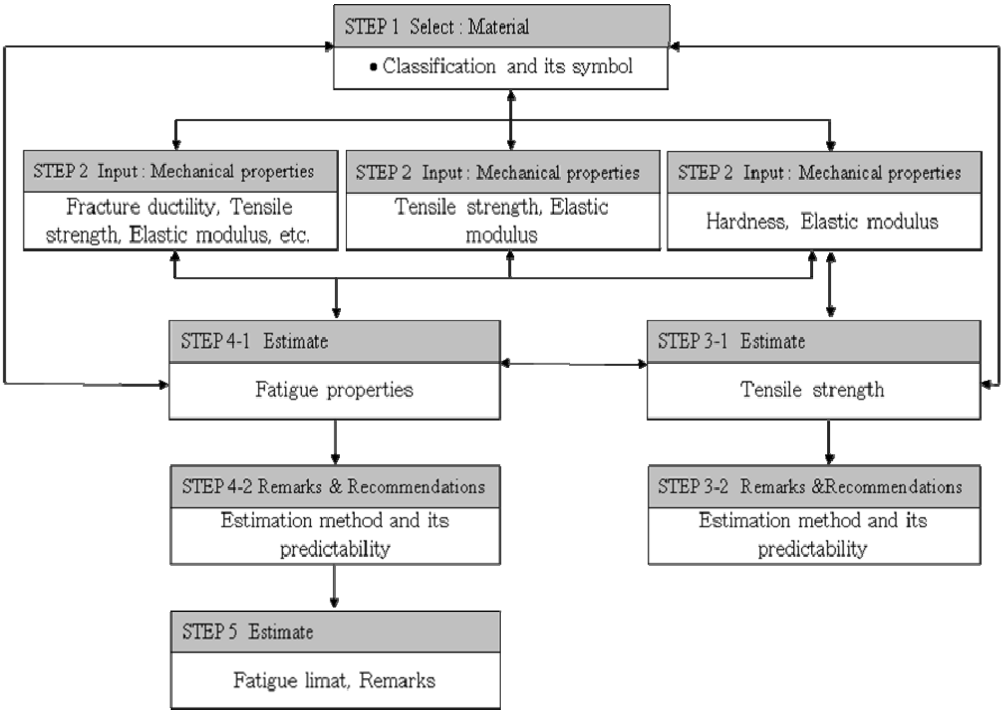

Fig. 2. Process flow of the expert system developed in this study

At step 2 in Fig. 2, users are to input some known knowledge about the mechanical properties of material, as shown in Fig. 3 (b). In this step, if the hardness is inputted, tensile strength can be estimated in next step, step 3. The elastic modulus and tensile strength of material are basic and essential for inferring fatigue properties using estimation method.

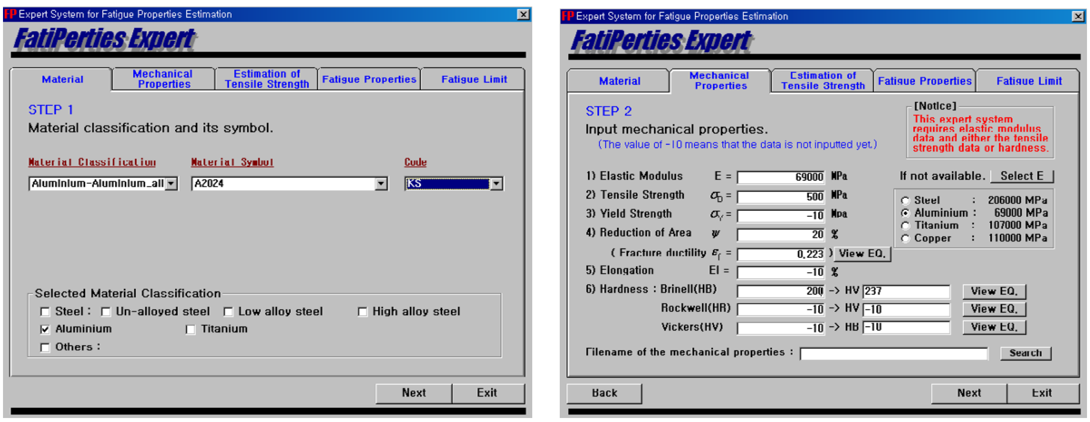

Fig. 3.(a) Screen of step 1 for inputting material classification and its symbol; (b) Screen of step 2 for inputting mechanical properties of material

At step 3 in Fig. 2, users can estimate tensile strength from the hardness of material with 2 options, as shown in Fig. 4 (a). First option is to use the expert system which chooses the most appropriate estimation method for the material to be analyzed, and second option is that users directly select one among 5 estimation methods listed. The expert system shows equation used in estimation and its application range by pressing "View EQ." button in the screen and the details of the estimation results by pressing "Remarks & Recommendations" button in the screen if the expert system is used.

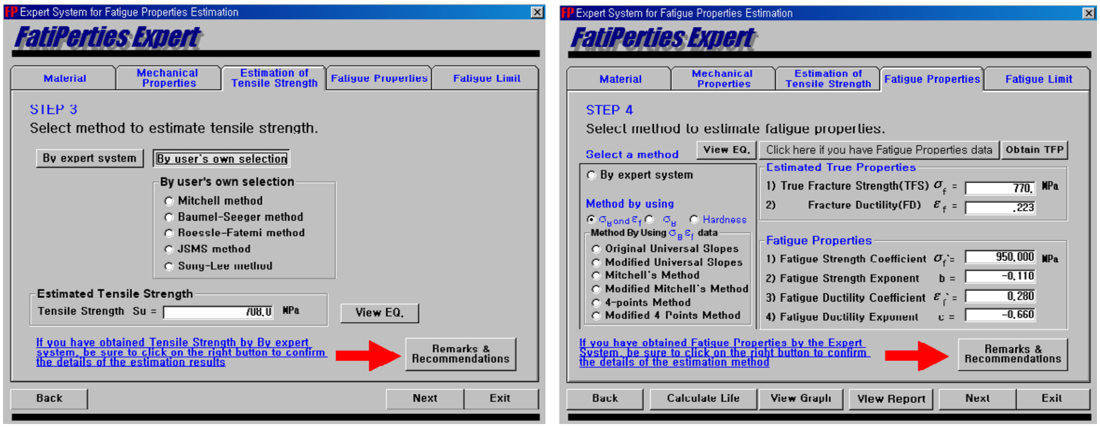

Fig. 4. (a) Screen of step 3 for estimating tensile strength of material; (b) Screen of step 4 for estimating fatigue properties of material

At step 4 in Fig. 2, users can obtain fatigue properties with 3 options, as shown in Fig. 4 (b). First, the users without some prior knowledge about fatigue can estimate fatigue properties using the expert system by the inputted mechanical properties or/and the estimated tensile strength which chooses the most appropriate estimation method for the material to be analyzed. Second, users who know estimation methods and its application range well can calculate fatigue properties by selecting one of the listed estimation methods, directly. The list will be different according to the inputted or/and estimated mechanical properties, that is, fracture ductility and tensile strength, tensile strength or hardness. Third, users can directly input fatigue properties if he/she know them. This option can be utilized for showing the difference between the inputted and estimated fatigue properties by pressing "View Grape" button for graphical comparison or "View Report" button. By pressing "Remarks & Recommendations" button in the screen, users can know the estimation method inferred by the expert system and its accuracy, total predictability, and application range. Clicking "Calculate Life" button enables to calculate fatigue life corresponding to the inputted total strain range and users can obtain the list of all "the inputted total strain range vs. fatigue life".

At step 5 in Fig. 2, users can obtain fatigue limit for axial loading with 2 options, as shown in Fig. 5. First, users can directly input the known fatigue limit. Second, users can estimate fatigue limit by the expert system. Users can compare the known fatigue limit with the estimated fatigue limit by pressing "Final Report" button. By clicking "Final Report" button, users can know all the inputted and estimated information. By clicking the "Remark" button, users can see the method used to estimate the fatigue limit.

The expert system allows users to move back or forth freely between each step if any information is inputted or estimated wrongly, as shown in Fig. 6. This process helps users easily to try for various cases by re-inputting all information or modifying some information inputted.

The developed expert system for estimating fatigue properties is designed to be linked to the developed expert system for fatigue strength assessment integrated, as shown in Fig. 7, and this expert system is composed of 4 phases for fatigue strength assessment of mechanical structures, as shown in Fig. 8.

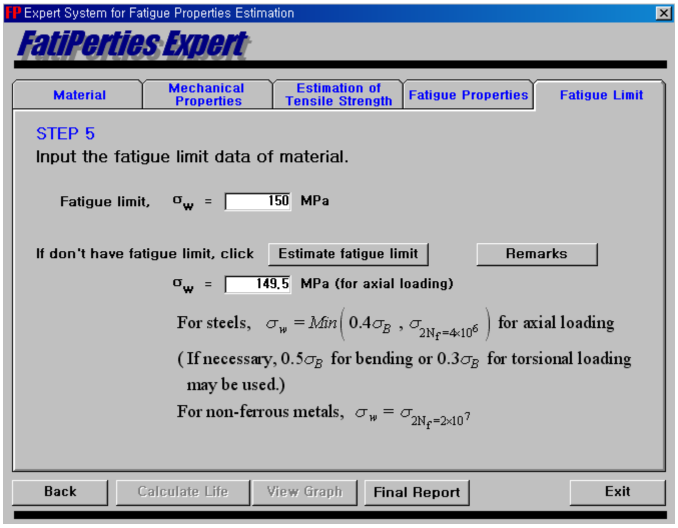

Fig. 5. Screen of step 5 for obtaining fatigue limit of material

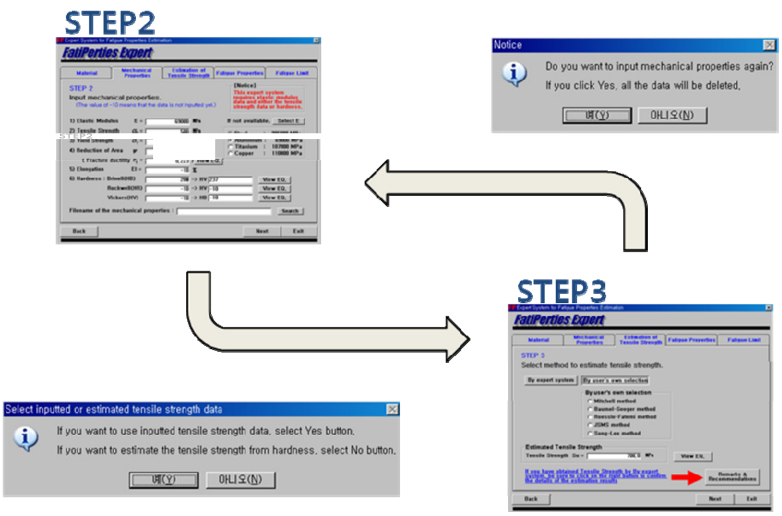

Fig.6. Screen of process for moving back or forth freely

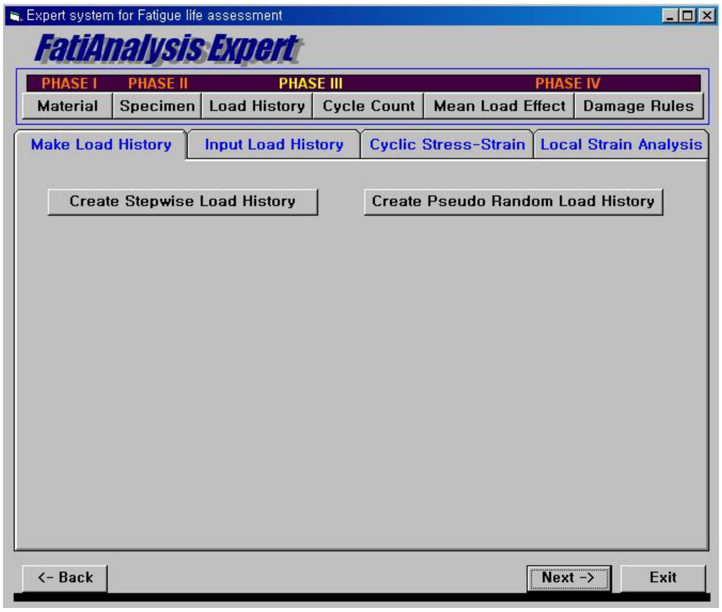

Fig.7. The developed expert system for fatigue strength assessment system

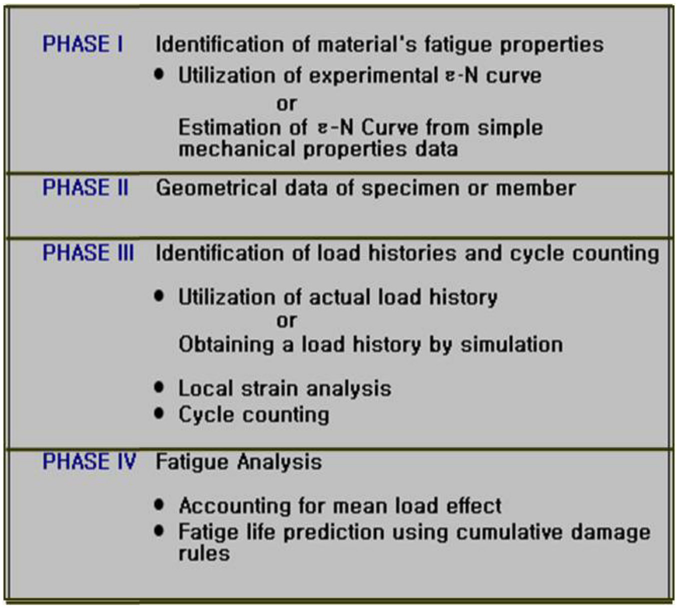

Fig. 8. Details of each phase in the developed expert

4. Conclusions

The fatigue strength assessment which is essential for the design of reliable mechanical structures and components, needs accurate fatigue properties of materials used in the structures or components. As the fatigue test for obtaining fatigue properties requires a lot of time and effort, there have been many attempts to estimate fatigue properties from simple tensile data. In this study, the expert system for estimating fatigue properties from simple tensile properties or/and hardness is developed so that mechanical designers can easily obtain fatigue properties regardless of their knowledge about fatigue. The expert system developed can use ten estimation methods suggested until now, especially including estimation methods using hardness. The expert system provides users with the most appropriate estimation method suitable for the material to be analyzed by considering accuracy and total predictability of estimation method and level of their knowledge about fatigue in inference.

The expert system developed has various user friendly functions such as graphical and descriptive outputs, and easy modification of inputted data by moving back or forth freely between each step. As commercial softwares are used, expert system will be easily upgraded corresponding to OS upgrade. The powerful integrated expert system for fatigue strength assessment could be developed by linking a module for estimating fatigue properties. The integrated expert system helps ordinary mechanical designers easily to design reliable mechanical structures or components by performing the fatigue strength assessment.

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References

[1] Liebowitz J. Expert systems: a short introduction. Eng. Fract. Mech. 1995;50:601–7.

[2] Komai K, Minoshima K, Koyama M. Development of diagnostic expert system for environmentally assisted cracking (EXENAC) and importance evaluation of knowledge in inference. Trans. JSME (A) 1991;57:188–94 [in Japanese].

[3] Minoshima K, Yamasaki N, Komai K. Development of expert system for fractagraphy of environmentally assisted cracking. Trans. JSME (A) 1994;60:34–40 [in Japanese].

[4] Liao TW, Zhan ZH, Mount CR. An integrated database and expert system for failure mechanism identification: part I —automated knowledge acquisition. Eng Failure Anal 1999;6:387–406.

[5] Liao TW, Zhan ZH, Mount CR. An integrated database and expert system for failure mechanism identification: part II — the system and performance testing. Eng Failure Anal 1999;6:407–21.

[6] McMahon CA, Williams JHS, Brown K, Sisson J, Davies J, Devlukia J. Knowledge based systems for design for fatigue. In: Fatigue '90: Proceedings of the Fourth International Conference on Fatigue and Fatigue Threshold, Honolulu, 1990:2461-6.

[7] McMahon CA, Banerjee S, Williams JHS, Devlukia J. Hypertext and expert systems application in fatigue assessment and advice, automation in fatigue and fracture; testing and analysis. ASTM STP 1994;1231:634–47.

[8] Ishikawa H, Dai X. Development of an expert system for evaluating fatigue strength (rotary bending fatigue of notched bar). JSME Int. J. (A) 1994;37:161–5.

[9] Dai X, Ishikawa H. Development of expert system for fatigue design (an object-oriented approach to knowledge management for design process). Trans JSME (A) 1994;60:1885–91 [in Japanese].

[10] Lee KY, Liebowitz H. An expert system in fracture mechanics. Eng. Fract. Mech. 1995;50:609–29.

[11] Lee SJ, Song JH, Ha JS. Fatigue life predictions for variable load histories — part II: computer software for predictions of fatigue crack initiation life. Trans KSME 1988;12:1350–7 [in Korean].

[12] Park JH, Song JH. Development of fatigue strength database. Trans KSME 1998;22:1947–55 [in Korean].

[13] Jeon WS, Song JH. An expert system for estimation of fatigue properties of metallic materials. International Journal of Fatigue 2002: 24: 685–698

[14] Kim YH, Song JH, Park JH. An expert system for fatigue life prediction under variable loading. Expert Systems with Applications 2009:36:4996–5008.

[15] Manson SS. Fatigue: a complex subject-some simple approximation. Exp Mech 1965;5:193–226.

[16] Mitchell MR. Fundamentals of modern fatigue analysis for design: fatigue and microstructure. Metals Park, OH: Americal Society For Metals 1979: 385–437.

[17] Muralidharan U, Manson SS. A modified universal slopes equation for estimation of fatigue characteristic of metals. J Eng Mater Tech 1988;110: 55–88.

[18] Bäumel Jr A, Seeger T. Metals data for cyclic loading, supplement I. Amsterdam: Elsevier Science Publishers; 1990.

[19] Ong JH. An improved technique for the prediction of axial fatigue life from tensile data. Int J Fatigue 1993;15:213–9.

[20] Roessle ML, Fatemi A. A strain-controlled fatigue properties of steels and some simple approximations. Int J Fatigue 2000;22:495–511.

[21] Park JH, Song JH. New estimation method of fatigue properties of aluminum alloys. Trans ASME 2003;125:208–14.

[22] Meggiolaro MA, Castro JTP. Statistical evaluation of strain-life fatigue crack initiation predictions. Int J Fatigue 2004;26:463–76.

[23] Lee KS, Song JH. Estimation methods for strain-life fatigue properties from hardness. International Journal of Fatigue 2006:28:386-400.

[24] Park JH, Song JH. Detailed evaluation of methods for estimation of fatigue properties. Int J Fatigue 1995;17(5):365–73.

[25] Kim KS, Chen X, Han C, Lee HW. Estimation methods for fatigue properties of steels under axial and torsional loading. Int J Fatigue 2002; 24:783–93.

[26] Lee JK, Song YU, Development of expert system using UNIK. Bupheungsa 1996;105–41 [in Korean].